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Tidal current turbines glance at the past and look into future prospects in Malaysia

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ABSTRACT

Periodic changes of water levels, and associated tidal currents, are due to the gravitational attraction forces between the Earth, the Sun and the Moon. These changes can be transformed to a renewable energy resource called Tidal Current Energy. A number of resource quantization and demonstration studies have been performed throughout the world and it is believed that offshore ocean energy sector will benefit from this emerging technology. In this study, a set of basic definitions which are relevant to this technology are presented with an overview on the main tidal turbine schemes and the mooring methods that in use. A review of the current development and their fields of applications are outlined. The Blade Element Momentum BEM method and the Computational Fluid Dynamics CFD are discussed. The last section highlights the importance of this technology and its applicability in Malaysia. Other renewable energy resources in Malaysia are highlighted and discussed as well.

Contents

1. Introduction

Tidal energy is the only type of energy which comes from the relative motions of the Earth–Moon system, and to a lesser extent from the Earth–Sun system. The tidal movements are cyclic variations in the level of the seas and oceans [1]. The tidal forces produced by the Moon and Sun, in amalgamation with Earth's rotation, are responsible for the generation of the tidal movements (Fig. 1), [2]. The magnitude of the tide at a given location is the result of the changing positions of the Moon and Sun relative to the Earth, the effects of Earth rotation, and the local shape of the sea floor and coastlines [3]. Because the Earth's tides are

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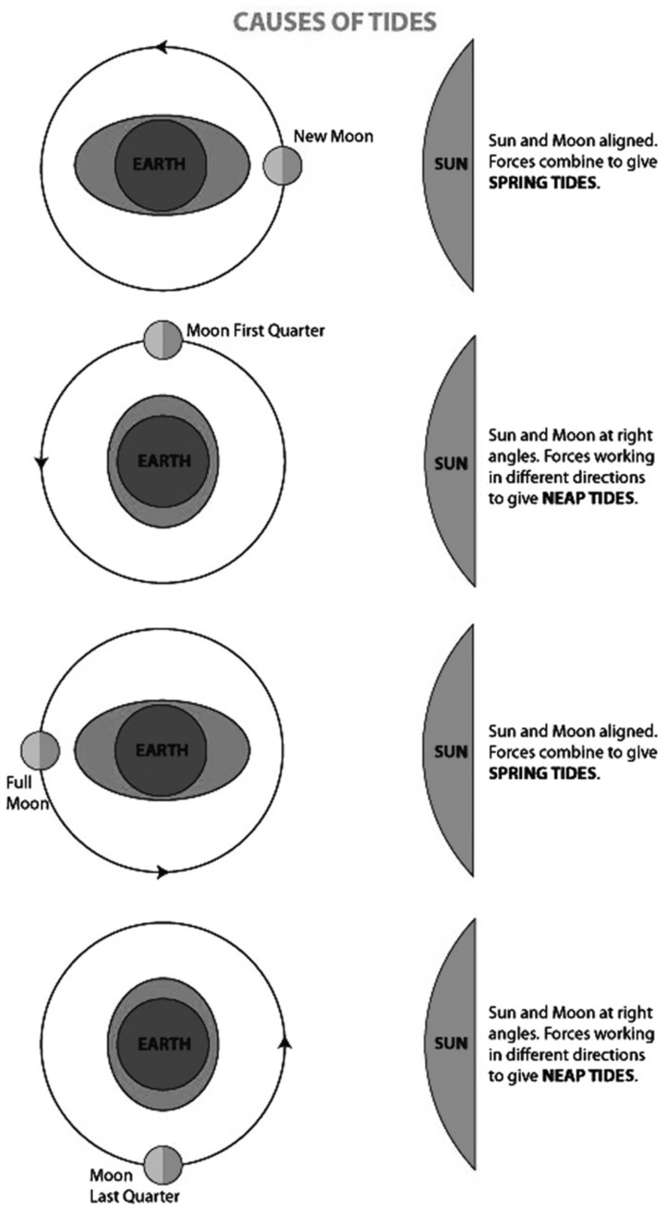

Fig. 1

caused by the tidal forces due to gravitational interaction with the Moon and Sun, and the Earth's rotation, tidal power is basically never-ending and can be classified therefore as a renewable energy source. Tidal energy extracting devices use this phenomenon to generate energy. The stronger the tide, either in water level height or tidal current velocities, the greater the potential for tidal energy generation.

Land-based renewable energy technologies are already facing limitations due to conflicts over land-use, so the seas and oceans offer enormous open spaces where prospect new energy technologies could be deployed on a magnificent scale, without impact on either the environment or on other human activities [4]. Debatably, unless we develop and use offshore renewable energy resources we will not be able to meet our future energy needs without continuing to consume escalating quantities of fossil fuels; this is the main argument for investing in these innovative and so far little-developed renewable energy technologies [5]. However, offshore renewable energy resources are generally more expensive and difficult to harness than the on-land resources, which is why experience up to now with them is quite limited [6]. There is a vicious circle at work in that the expenses of harnessing offshore energy technologies will only be reduced once they are perfected and then deployed on a large scale, so that the high costs involved can be shared by a large deployed generating capacity, but while costs and risks are high there is no incentive for large scale deployment [7].

Tidal energy technologies under development have its roots in investigational work that started in the 1970s after the first surge of interest in renewable energy alternatives following the oil crisis of that era. The common factor between these eras is that the development of renewable energy technologies was supported politically; but of course today the apprehension is for the damage to the environment from greenhouse gases if we carry on to burns even the known reserves of oil in their entirety [8].

There are basically two methods of generating electricity from tidal movement: by building a tidal barrage across an estuary or a bay in high tide areas, or by extracting kinetic energy from free flowing tidal current
[9–11].

Tidal barrages make use of the potential energy in the difference in height between high and low tides. Tidal barrages are a deep-rooted, technically-proven concept which fundamentally involves a structure with gated sluices and low-head hydro turbines (Fig. 2), [12]. This system has been in operation at "La Rance" on the northern French coast for more than 40 yr. Barrages are essentially dams across the full width of a tidal estuary, and suffer from very high civil infrastructure costs, a worldwide shortage of viable sites, and environmental issues [13].

Tidal current systems make use of the kinetic energy of moving water to power turbines, in a similar way to windmills that use moving air. This method is gaining in popularity because of the lower cost and lower ecological impact compared to barrages. Most of the proposed tidal current turbines resemble submerged wind turbines but there are also substantial differences in appearance stemming from the much larger structural loads these devices are subjected to [14].

Modern advances in turbine technology may eventually see large amounts of power generated from the ocean, especially tidal current using the tidal current designs. Tidal current turbines may be arrayed in high velocity areas where natural tidal current flows are concentrated. Such flows occur almost anywhere where there are entrances to bays and rivers, or between land masses where water currents are concentrated [15]. Many tidal sites are relatively bi-directional; however, some sites can have flow reversal of 20° or more away from 180° such as the flow around islands [16] and headlands [17]. This paper discusses the background to the development of a unique and novel technique for renewable energy generation using the kinetic energy of tidal currents.

2. Background of hydrokinetic energy conversion

The process of hydrokinetic energy conversion involves utilization of kinetic energy contained in river streams, tidal currents, or other man-made waterways for generation of electricity. This emerging type of renewable energy technology is being strongly recognized as an exceptional and unconventional solution that falls within the areas of both in-land water resources and offshore energy resources. In contrast to conventional hydroelectric plants, where an artificial hydraulic head is created using dams or penstocks, for large-hydro and micro-hydro, respectively, hydrokinetic converters are constructed without significantly altering the natural path of the water stream [18]. With regard to ocean power exploitation, these technologies can be arranged in

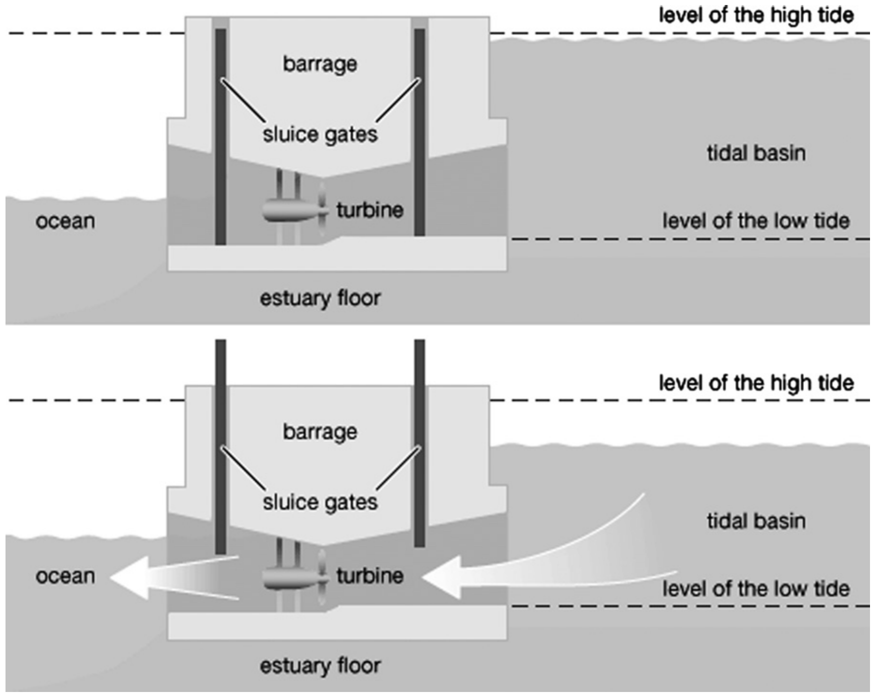

Fig. 2

multi-unit array that would extract energy from tidal currents as opposed to tidal barrages where stored potential energy of a basin is harnessed. While modularity and scalability are attractive features, it is also expected that hydrokinetic systems would be more environmentally friendly when compared to conventional hydroelectric and tidal barrages.

The basic physical principles for extracting hydrokinetic energy from tidal currents are virtually similar to those for wind. Just as with wind, we will need to use lift dependent, rather than drag based, devices as those are the only ones that will be efficient enough to be cost effective. Hence, there are three main lift-based mechanisms currently being promoted, evaluated and tested, the axial flow rotor which is favored generally for wind turbines and the cross-flow rotor. [19]

The environment that tidal current turbines will operate in is very different from that experienced by wind turbines, and there are some rather difficult problems associated with installation, survivability and maintenance which needs to be solved before true commercial exploitation can be achieved [20]. Despite the similarity with wind turbines, there are major differences in the engineering of a tidal current turbine because of the higher density of water compared with air, 832 times the density of air, and the much slower speed of rotation [21]. As a result, the loadings experienced by the structure of a tidal current turbine are quite different from those on a wind turbine; they are mostly bending forces due to lift rather than the gravity and centrifugal forces that dominate for a wind turbine rotor [22].

Therefore tidal current turbines, regardless of rotor configuration, bear large forces and perhaps the dominant engineering challenge is structural, to produce a system which will reliably resist large loads. Not only have the rotor blades got to handle the large lift forces generated in quite a small area, but the entire structure has to have a foundation which will reliably resist the overall reaction thrust from kinetic energy extraction. These structural issues are more complicated by complex dynamic loadings that can occur due to turbulence in the flow, passing waves, velocity shear, vortex shedding, static pressure variations as rotor components move vertically through the water column, etc. The one other major difference using water as the working fluid rather than air is the phenomenon of cavitations which limits the rotor tip velocity that can practically be used near the surface to about 10 or 12 m/s [23]. Cavitations degrades hydrofoil performance by causing boundary layer separation on the suction side, which is an effect similar to stalling [24].

2.1. Energy extracted and turbine efficiency

The maximum power available to a turbine is the kinetic energy of the fluid in a stream tube whose diameter is equal to the diameter of the turbine. This power is expressed as a function of the density of the medium ρ, the area of the stream tube, A at the point where it meets the turbine and of the flow velocity, V as can be seen in Eq. (1) [25]

$$E_{max} = \tfrac{1}{2}\rho A V^3 \tag{1}$$

However, a tidal current turbine can only extract a fraction of this power due to losses and Eq. (1) is modified as follows:

$$E_{max} = C_p \tfrac{1}{2}\rho A V^3 \tag{2}$$

C_p, is known as the power coefficient and is essentially the percentage of power that can be extracted from the tidal current and takes into account losses due to Betz's law and those assigned to the internal mechanisms within the converter or turbine [25]. For tidal current turbine, C_p is estimated to be in the range 0.35–0.5 [26].

Different turbine designs have different efficiencies and therefore different power outputs [20]. This allows the efficiency of the turbine, expressed as a percentage, to be defined as:

$$\eta = \frac{E}{E_{max}} 100 \tag{3}$$

where, η is the turbine efficiency and E is the power output of the turbine.

2.2. Tidal current turbine schemes

Tidal energy device utilizes the natural ebb and flow of coastal tidal waters caused mainly by the interaction of the gravitational fields of the Earth, Moon and Sun. The fast tidal currents are often magnified by topographical features, such as headlands, inlets and straits, or by the shape of the seabed when water is forced through narrow channels. The tidal current turbines which utilities these currents are broadly similar to submerged wind turbines and are used to exploit the kinetic energy in tidal currents. Due to the higher density of water, this means that the blades can be smaller and turn more slowly, but they still deliver a significant amount of power. To increase the flow and power output from the turbine, concentrators or shrouds may be used around the blades to streamline and concentrate the flow towards the rotors. Two major types of tidal stream turbines were identified in the literature, they are:

- *Axial turbines*: turbines in which the direction of flow is parallel to the axis of rotation, and commonly referred as "Horizontal Axis" turbines [18] (Fig. 3). This device extracts energy from moving water in much the same way as wind turbines extract energy from moving air. Devices can be housed within ducts to create secondary flow effects by concentrating the flow and producing a pressure difference.
- *Cross flow turbines*: turbines in which the direction of flow is across the axis of rotation are commonly referred to as "vertical axis" turbines, since their axis is usually vertical [18] (Fig. 4). However they are more accurately described as "cross flow" since their distinguishing feature is the fact that the direction of flow is across the axis of rotation, which may be horizontal.

Further to the categories of devices identified above, there is also a range of methods to fix the converter to the seabed [27]:

- *Seabed Mounted Gravity Base*: this is physically attached to the seabed or is fixed by virtue of its massive weight. In some cases there may be additional fixing to the seabed.
- *Pile Mounted*: this principle is analogous to that used to mount most large wind turbines, whereby the device is attached to a pole penetrating the ocean floor. Horizontal axis devices will often be able to yaw about this structure. This may also allow the turbine to be raised above the water level for maintenance.
- *Hydrofoil Inducing Down force*: this device uses a number of hydrofoils mounted on a frame to induce a down force from the tidal current flow. Provided that the ratio of surface areas is such that the down force generated exceeds the overturning moment, then the device will remain in position.

Floating: two types

- *Flexible mooring*: the device is tethered via a cable/chain to the seabed, allowing considerable freedom of movement. This allows a device to swing as the tidal current direction changes with the tide.
- *Rigid mooring*: the device is secured into position using a fixed mooring system, allowing minimal leeway.

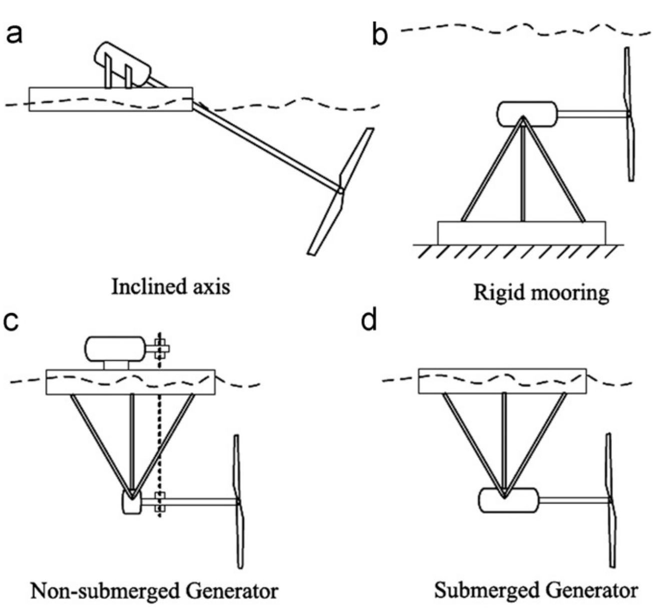

Fig. 3

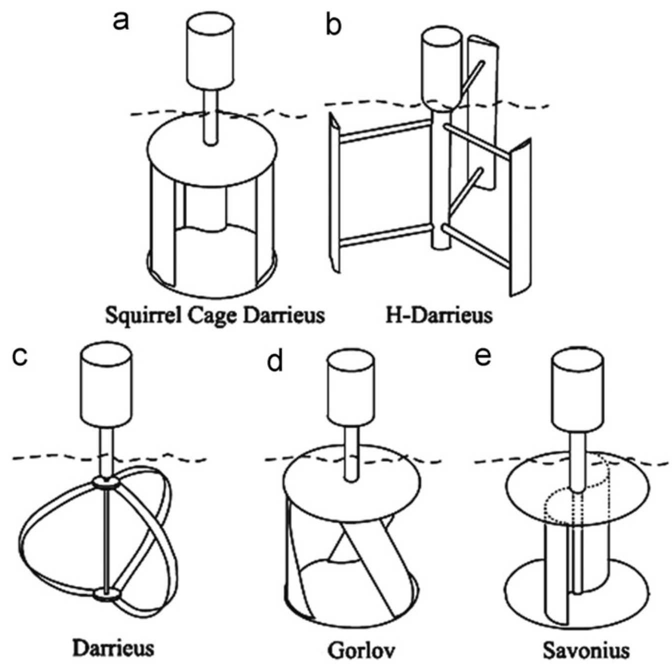

Fig. 4

3. Current development

The development of tidal current turbines is evident in the recent proposed projects around the world with a significant amount of extracted energy. The expected timescales for most of these projects are within 5–10 yr and demonstrate substantial confidence in the technology. The more advanced proposals typically plan to use variants of axial flow turbines. Although it is suggested that larger powers can be captured with cross flow turbines, however, typically these are less effective at capturing energy for a given swept area.

3.1. Axial tidal turbines

There is no total agreement on the form and geometry of the conversion technology itself. Wind-power systems are almost entirely axial flow rotating turbines. In these systems the axis of rotation is parallel to the direction of the current. Many developers favor this geometry for tidal current conversion. Cross flow turbine systems, in which the axis of rotation is perpendicular to

the direction of the flow, have not been rejected though. The majority of the tidal turbine prototypes currently operating employ this design approach. A general survey of some of these machines along the last few years is presented next:

- *Kvalsund turbine, HS300*: Hammerfest Strom [28] selected Kvalsund in Northern Norway as test site for the Company's prototype HS300. HS300 was used as a proof of concept turbine from 2003 to 2009. Although it is a prototype, a horizontal axis turbine with a reported capacity of 300 kW was connected to the grid on 13th of November 2003. The Kvalsund turbines have single rotors that have three variable-pitch blades that can be rotated 180° to produce power from the tidal current ebb and flow.
- *Seaflow*: a 300 kW horizontal axis turbine was installed by Marine Current Turbines off the coast of Lynmouth, Devon, England, in 2003 [29]. The 11 m diameter turbine generator was fitted to a steel pile which was driven into the seabed. The rotor is made from composite materials and is 11 m in diameter with full span pitch control. It can be reversed by pitching the blades through 180° in order to operate with the current in either direction. As a prototype, it was connected to a dump load, not to the grid.
- *SeaGen*: a full size prototype (Fig. 5) was installed by Marine Current Turbines in Strangford Lough in Northern Ireland in April 2008, following the trial Seaflow turbine [29]. The turbine began to generate around 150 kW into the grid for the first time on the 17th of July 2008. The initial set of blades suffered some damage and new reinforced blades were installed in September 2008. Finally, the turbine began to generate at full power, about 1.2 MW, in December 2008. It is currently the only commercial scale device to have been installed anywhere in the world as can be seen in [29].
- *Verdant turbine*: since April 2007 Verdant Power has been running six 35-kilowatt horizontal axis turbines were installed in a New York's East River with currents that flow at a rate of up to 4 knots [30]. The six turbines currently produce electricity that powers a grocery store and parking garage nearby. Verdant is planning to add more turbines to the channel, which should produce enough electricity to power 4000 homes. It was the first major tidal-power project in the United States. Equipment to monitor the surrounding aquatic life where attached to the turbine.
- *OpenHydro turbine*: is a 250 kW open-centered horizontal axis turbine, its innovated simple design means that it can withstand harsh ocean tides, while having no impact on marine mammals since it has no oils that can leak, no exposed blade tips and a significant opening at its centre [31] (Fig. 6). Recently, OpenHydro have installed the first commercial-scale in-stream tidal turbine in Canada's Bay of Fundy. The one-megawatt 'open centre' turbine has been deployed on the site of the future Fundy Ocean Research Centre for Energy in the Minas Passage [14].
- *AK1000*: a device thought to be the largest tidal turbine of its type to be built in the world has been described by its developer as "simple and robust" [32] (Fig. 7). The AK1000, by Atlantis Resources stands 18 m height and is capable of generating 1 MW, enough to power at least 1000 homes. Its blades, turning at six to eight revolutions per minute pose no threat to marine life. The turbine will be installed at the European Marine Energy Centre in Scotland's Orkney Islands.

Fig. 5

3.2. Cross flow tidal turbines

Cross flow turbines that operate in tidal currents are based on the same principles as the land based Darrieus turbine. The Darrieus turbine is a vertical axis turbine, whose axis of rotation

Fig. 6

Fig. 7

meets the flow of the working fluid at right angles. In tidal current applications, cross flow turbines allow the use of a vertically orientated rotor which can transmit the torque directly to the water surface without the need of complex transmission systems or an underwater nacelle. The vertical axis design allows the harnessing of tidal currents from any direction, facilitating the extraction of energy not only in two directions, the incoming and outgoing currents, but making use of the full tidal ellipse of the flow [33]. In this kind of turbines as in the horizontal axis ones the rotation speed is very low. A general survey of these machines along the last few years is presented next:

- *The Enermar Project—Italy*: the core of the Enermar project is the patented Kobold turbine. Among its main characteristics, the Kobold turbine has a very high starting torque that makes it able to start spontaneously even in loaded conditions [34]. A study has been made to link the quantity of energy that can be obtained in a year from the site where the turbine is currently installed, the Strait of Messina, to Ganzirri. The result indicates that about 22,000 kW per hour of useful energy can be extracted each year. In this site, considering the currents in the area, the total extractable energy is equal to 538 Gwh [24].
- *EnCurrent generation systems*: the technology is based on the Darrieus wind turbine. With the 5, 10 and 25 kW EnCurrent Power Generation Systems available in the marketplace, the company is working to expand its customer base for these products in tandem with scaling up its core technology in order to provide 125 and 250 kW models [35]. These larger models enable the construction of in-stream power generation plants with capacities of up to 5 MW.
- *Blue Energy Turbine*: the design of the Blue Energy Turbine [36] requires no new construction methodology; it is structurally and mechanically straightforward. The transmission and electrical systems are similar to thousands of existing hydro-electric and wind turbine installations. The rotation of the turbine is unidirectional on both the ebb and the flow of the tide. A turbine is expected to be about 200 kW output power. For large scale power production, multiple turbines are linked in series to create a tidal fence across an ocean passage or inlet. Blue Energy has active on the ground business development files in Scotland, Chile, Indonesia, the Philippines, New Zealand, Alaska, India, Indonesia, and Iceland. These are large scale tidal bridge projects [30].
- *The Gorlov Helical Turbine*: this vertical axis turbine consists of one or more long helical blades that run along a cylindrical surface like a screw thread. The blades provide a reaction thrust that can rotate the turbine faster than the water flow itself. The Gorlov is self-starting and can produce power from water current flow as low as 1.5 m/s [37]. Due its axial symmetry, the turbine always rotates in the same direction, even when tidal currents reverse direction. This is a very important advantage that simplifies design and allows exploitation of the double action tidal power plant. A single Gorlov turbine rated power is 1.5 kW for 1.5 m/s water speed and 180 kW for 7.72 m/s [33].

4. Computational techniques review

The main computational techniques are used for the study and design of tidal turbines: those employing the Blade Element Momentum BEM method and software that makes use of Computational Fluid Dynamics CFD formulations. Technological advances have improved the accuracy of codes resulting in several powerful tools which, when used either singly or in conjunction with each other, can provide vital information as to the performance of a tidal current turbine in varying flow conditions.

4.1. Blade element momentum BEM method

The basis of turbine performance can be considered in terms of the performance of an infinitely thin disk that acts to convert the kinetic energy of an onset wind or tidal current into rotational motion [38]. The disk can be analyzed in terms of the work done to convert axial momentum into rotational momentum.

The momentum conversion is controlled by the orientation and shape of the rotor blade [38]. The effective flow containing the axial free stream and rotational flow determine the effective angle that the wind or current should attack the blade. The blade element analysis requires knowledge of the deceleration of the free stream and the imposed tangential component of velocity [39].

Coupling together the momentum analysis and the blade element analysis using an iterative approach allows the performance at a given tip speed ratio and a given radius to be calculated [40]. A span-wise integration produces the total generated axial thrust, torque and power. The BEM method provides a rapid technique for analysis and is therefore suitable for blade geometry optimization. Information gained from a BEM analysis consists of power, thrust and torque data for the tidal turbine [41]. The influence of cavitations can also be included in the analysis. Computational times are very quick, of the order of fractions of seconds, and as such use of this type of analysis is common at the preliminary design stage for a turbine [39].

Whilst overall performance data for the turbine is essential for design, it is also necessary to gain a more detailed understanding of the characteristics of the fluid flow around the device in order to optimize efficiency and energy capture.

4.2. Computational fluid dynamic CFD method

Computational fluid dynamics (CFD) uses numerical methods to solve equations that define the physics of fluid flow. There are many published researches that show the maturity of CFD analysis for tidal turbine applications. CFD is a generic term for the numerical calculation of both viscid and inviscid equations of motion, continuity and additional equations for calculations of turbulence, viscosity etc. [42]. The first important stage in the modeling of a tidal stream turbine is the prediction of its interaction with the moving water and the energy generated by the device [43]. These methods can provide detailed information about the characteristics of the local flow and hence performance of a marine current turbine in varying flow conditions. As well as obtaining the turbine performance data, CFD analysis found a solution for the downstream wake modeling for the tidal turbine in order to characterize the wake. This is essential in order to study the impact of an upstream turbine on the downstream ones, when these operate in a farm configuration, or for multiple rotors turbine schemes in terms of the interaction between rotors [44].

In 2D analysis, a number of Panel codes have been developed for foil analysis and design. The 2D analyses can be attained using most CFD programs. Section performance data includes the lift and drag coefficients of differing sections from which estimates of the power, thrust and torque on the turbine rotor and structure can be achieved [45]. One of the most prominent features of two dimensional codes is the fast computation time required to calculate section performance data [45]. This is useful, as lift and drag data for the blade sections is required for BEM analysis, and using a process which is computationally intensive to obtain such information would be counterproductive due to the swift calculations times of the BEM analysis [45].

Two dimensional section analyses are a powerful tool at the preliminary design stage for a tidal turbine, and should not be underestimated. It is apparent, however, that for more integral design information, a more complex code able to model more complex situations in three dimensions is required.

3D analyses are more computationally exhaustive than 2D analysis methods. 3D codes calculate the characteristics of each panel over the surface of the body under analysis to produce a pressure distribution and lift and drag data for the panel, and ultimately the body as a whole [45]. The selection of the correct panel distribution over the turbine model is vital with relation to the accuracy of the results and the time taken for each calculation.

The codes can be used to predict the cavitations inception on the turbine blades and also as a source of detailed distribution of blade loading for further structural calculations [45].

Although it is possible to predict cavitations inception, the use of 3D method which include the presence of cavitations regions requires significant use of empirical information to define cavitation bubble shape and analysis often becomes unstable and unsuitable for automated optimization process [46]. It is therefore apparent that more advanced numerical simulation of the area around the turbine is necessary for a full design.

The second main CFD method is the Reynolds Average Navier Stokes RANS Equations method. RANS equations are time-averaged equations of motion for fluid flow [47]. They are primarily used while dealing with turbulent flows. These equations can be used with approximations based on knowledge of the properties of flow turbulence to give approximate averaged solutions to the Navier–Stokes equations [44].

The nature of RANS equations leads to the need of a complex discrete mathematics technique as well as complex modeling with large numbers of elements. This often leads to complex mesh structures on which the equations must be solved, and building such meshes is time consuming.

5. Literature review of recent tidal turbine studies

A summarized review including journal and conference papers recently published are briefly commented next, in order to highlight the more relevant advances reported, concerning energy assessment, turbine design and optimization, device power output and efficiency.

A number of studies attempted to assess the available energy capacity of specific locations through the development of appropriate theoretical approaches. Blanchfield et al. [48] investigated the power potential of Masset Sound in Canada. They developed an approach applicable for a tidal channel linking a bay to the sea. Applying this, with the assumption of a constant depth averaged flow rate, it can be noticed that as more energy is extracted, the flow rate decreases; and at one point, increasing the number and/or size of tidal devices will reduce the power capture. For Masset Sound, the maximum average extractable power is about 54 MW. This would reduce the flow rate through the sound by 40% of the undisturbed flow while extracting 12 MW would keep the flow rate within 90% of its original value.

Brooks [49] looked at the tidal current energy resource in Passamaquoddy-Cobscook Bays. This has a high tidal range of 5.7 m and a 1 GW tidal barrage was proposed to be deployed. For tidal stream devices to achieve even a small fraction in such a site, they have to be located in areas of natural flow constriction, which raises the local flow speed. A numerical model was used to assess the expected estuarine and coastal flow circulation. The finite difference model examines velocity, temperature, and salinity fields for mass and momentum conservation. This was used to determine the power density with the highest value of 10 kW/m^2.

Sutherland et al. [50] employed a 2-D finite element model with turbines simulated in certain regions by increasing drag forces within Johnstone Strait in Canada, and compared this to the predictions with the analytical estimates of Garrett et al. [51]. Important comparisons were achieved and a significant conclusion is that available energy for a system that attempts to harness a maximum amount of tidal current energy has to aim to minimize any losses associated with drag effects of the turbine support structure. The authors made sure that turbines were deployed such that they did not deflect flow away to the other side of a channel or into another channel.

Garrett et al. [52] examined in detail the interaction between multiple tidal current turbines across a channel and showed that the Betz limit, $C_p = 16/27$, for maximum efficiency of a turbine in an infinite domain is increased by a factor of $(1-A/A_c)^{-2}$ in a channel in which A is the device area and A_c is the channel area. This is equivalent to the blockage correction that should be applied to tidal energy turbines tested within a towing tank as described by Bahaj et al. [23]. In a technical note by Garrett et al. [53] showed that a small number of tidal turbines might be the most efficient strategy, especially if allowance is made for the drag of the support structure.

Nicholls-Lee [3] suggested that a considerable performance advantage can be gained from using variable pitch blades. Adaptive materials may be beneficial when improving loading and performance of a free stream tidal turbine blade thus improving efficiency. Another relevant comment is that many tidal sites have relatively bidirectional flow. However, some sites may have flow reversal of over 20° from 180° such as the flow around islands and headlands. Nicholls-Lee et al. [22], discuss techniques for simulation based optimization of marine current turbines, including the relative benefits and disadvantages of such methods. Blade Element Momentum BEM codes, Computational Fluid Dynamics CFD and Finite Element analyses, and subsequently the coupling of such techniques, are considered. The significance of design, search and optimization with respect to complex fluid and structural modeling is also discussed.

Batten et al. [24]presented a methodology for the hydrodynamic design of horizontal axis marine current turbines. Due to the narrow blades and near 2D flow, the turbine can be modeled successfully using blade element momentum BEM theory. It is noted that suitable section performance data, which also include cavitation characteristics, are required for the detailed design of the marine current turbine blades. The authors demonstrate how blade pitch angle or changes in camber alter stall performance and delay the possibility of cavitation for marine current turbines. However, levels of acceptance of cavitation are currently not yet clear.

Egarr et al. [54] modeled a tidal turbine by using Computational Fluid Dynamics CFD validated against experimental data. This is the first stage in the process of optimizing a turbine to extract energy from the tide. The redevelopment of the flow downstream from the turbine has also been studied. An important conclusion of this work is that the authors found that CFD presented a good prediction of the power extraction of the turbine. Germain et al. [55] provided useful information for the hydrodynamic characterization of marine energy converter systems, their design and validation, including the procedure for the characterization of the wake of horizontal axis marine current turbines which has been of a great interest. Karsten et al. [20] examined the tidal power available for electricity generation from stream turbines placed in a particular location. This suggests that the greatest tidal power will be possible in channels where the product of the flow rate through the channel and the tidal amplitude at the entrance of the channel is large. This means that its application under the sea is completely suitable.

Bahaj et al. [56] presented a discussion on the characterization of the wake of horizontal axis marine current turbines. An experimental and theoretical investigation of the flow field around small-scale mesh disc rotor simulators is presented and wake characteristics of the rotor simulators have been measured.

Croft et al. [42]examine all aspects related to the installation of tidal stream turbines. These aspects range from determining the process necessary to reach consensus regarding installation of the device and surveying techniques necessary to obtain site related data through to numerical modeling.

McCann [57] shows a parametric study of the sensitivity of fatigue loading experienced by a tidal current turbine to the environment in which it operates. It has been found that the fatigue stress margins are observed to fall as low as 8% under certain environmental conditions which indicates that a detailed description of environmental conditions is needed in order to achieve an optimized design. Nicholls-Lee [58] used CFD to model the interactions of fluid-structure, and through practical testing in towing tanks and open water. The authors suggested that adaptive materials could be incorporated into tidal turbine blade design to increase efficiency. It is clear that optimizing the efficiency of a turbine would improve performance and inevitably reduce the cost of the electricity produced, making it a more competitive energy source. Whelan et al. [41] presented theoretical results for the case of a linear array of tidal stream turbines that account for the proximity of the free surface and the seabed. The theoretical results were compared to open channel flow experimental results. The flow field was first experimentally simulated using various resistance discs.

MacLeod et al. [59] describes the application of Computational Fluid Dynamics techniques to the problem in the modeling of tidal turbine wakes. Results for both one turbine alone and two turbines positioned in tandem are included. Features such as the increased flow recovery rate with higher ambient turbulence intensity levels and the slower recovery downstream of turbines with higher thrust coefficients are predicted much as expected.

Couch et al. [60] present results from a simplified one-dimensional analysis of the governing equations and demonstrate the significant upstream and downstream effect of energy extraction on velocity and elevation in a simple channel setup. Norris et al. [61] present detailed site information regarding the resource available, environmental characteristics, and meteorological data and also discusses some of the work being undertaken at the centre on data provision and interpretation, in particular regard to the tidal test site. For its tidal test site, the European Marine Energy Centre EMEC is currently developing Acoustic Doppler Current Profiler ADCP survey methodologies in order to address developers' needs for an appropriate picture of the raw energy [27].

6. Review of recent patented technologies

A summary list with the most relevant patents on tidal streams turbines, reciprocating tides, Blade interferences, kinetic energy, single/double rotor Systems, etc has been assembled and is shown in chronological order including a brief description of each issue.

Paul [62] invented a vertical axis swinging flap turbine for producing power from low speed fluid flows such as tidal flows. The present invention is designed to collect large amounts of energy from much slower fluid flows which will allow vast areas of coastal tidal waters to be considered that have these slower tidal flows, also this type of turbine will also operate for much longer periods during each tidal cycle, not only peak flow times. The turbine has upper and lower circular discs with vanes mounted on shafts arranged around the discs. The turbine turns in the same direction regardless of the flow direction. The turbine also has semi circular Savonius type blades which provide a high starting torque to ensure that the main turbine cannot stall. The turbine is provided with a bristle brush antifouling device to prevent marine growth that would increase drag on the discs.

Anthony [63] adapted a system to extract energy from flowing liquid. The system includes at least one vertically-extending vane adapted to move in response to the flowing liquid. The vane has a vertical length wherein at least a portion of the vane can be positioned below a surface of a body of liquid such that the vane forms a swept area defined at least partially by the vertical portion of vertical lengths of the vane positioned below the surface. The system further includes a mechanism adapted to selectively vary the swept area. Richard [64]described a turbine adapted to be constrained within a flow of fluid. The turbine comprises a stator adapted to be constrained within a flow of fluid, and a rotor defining an aperture and having a plurality of rotor blades protruding from a peripheral region of the rotor into the aperture. The rotor is adapted to be rotatable mounted to the stator such that movement of fluid through the aperture causes rotation of the rotor relative to the stator. Electricity is generated as a result of rotation of the rotor relative to the stator.

Kenneth [65] presented a water turbine comprising a rotor having two blades extending from it, the blades being cyclically adjusted during rotation about an axis perpendicular to the axis of rotation of the rotor, the cyclic adjustment of each blade being affected by contact of a protrusion connected to each blade with a stationary component of the turbine. The stationary component of the turbine may be rotated by a fin or sensor so as to be correctly aligned with the direction of the fluid flow. The plane of rotation of the rotor may be horizontal or vertical.

Clayton et al. [66]invented a floating platform capable of supporting a turbine assembly. The platform and turbine assembly may be configured so as to resist drag. Drag may be absorbed by holding members attached to the present invention above and below the moment center. Furthermore a pivoting cable may be incorporated in the turbine assembly whereby the turbine assembly is moveable and thereby able to absorb drag that is exercised upon a non-moveable rigidly positioned turbine as excessive torque on the turbine rotors. The turbine assembly is further pivoted between vertical (working) and horizontal (transportable) positions.

Kent [67] provided an aquatic turbine apparatus including a rotor coupled to one or more sets of blades, a bearing for rotationally supporting the rotor on a support arrangement and an energy pickup arrangement disposed at least in part in the rotor for generating energy when the rotor rotates in operation relative to the support arrangement in response to tidal currents acting upon the one or more sets of blades. The one or more sets of blades are disposed in a form of a helical-blade rotor, for example a Darrieus-type rotor, operable to extract energy from tidal currents irrespective of turbulence and direction of the currents.

Aaron et al. [68] provided a method of controlling the alignment of a tidal stream energy device. The method includes the steps of: providing a reference profile for the variation of tidal current velocity with time at the tidal stream energy device; measuring a profile for the present variation of tidal current velocity with time at the tidal stream energy device; correlating the reference and measured profiles to identify a period of slack water; and changing the alignment of the tidal stream energy device during the identified period of slack water so that the device is appropriately aligned to generate energy from a following period of tidal flow.

Frederick [69] described an annular single or multi-rotor double-walled turbine. The turbine includes an outer shroud, an

inner shroud, and a plurality of drive-shafts. The turbine also includes a plurality of rotors coaxially attached to the plurality of drive-shafts at spaced intervals. Each of the plurality of rotors comprises a plurality of turbine blades extending between the inner and outer shrouds. Each of the plurality of turbine blades comprises a face. The inner shroud and the outer shroud form a continuous channel for directing a fluid entering the turbine towards the faces of the turbine blades and for directing fluid discharged from a first of the plurality of rotors to the remaining rotors. The channel greatly improves efficiency of power extraction from all augmented and non-augmented fluid streams.

Jarlath [70] presented an invention which is directed to a turbine comprising a pair of opposing end discs concentrically aligned with a central axis of the turbine and a plurality of blades extending between the end discs. At least one end discs is adapted for engaging with a generator for generating power. The plurality of blades rotates in a single direction when exposed to fluid flow and thereby rotates the pair of opposing end discs. The plurality of blades are interconnected by at least one faired ring oriented parallel to the pair of opposing end discs and intersecting the plurality of blades, wherein the at least one faired ring is in concentric alignment with the central axis. The present invention further comprises a method for generating power comprising engaging the turbine with a generator to create a turbine generator unit and deploying the turbine generator unit within a fluid flow.

Ian et al. [71] presented an invention which is directed to overcome the problems associated with complex marine turbines and provide a simple, robust and economic design. The blades may be located downstream of the turbine body and means are provided to enable relative rotational movement between the support and the turbine such that the turbine aligns with the fluid flow and at least one bearing is configured to be in contact with the fluid. There may also be provided an electrical connection means that comprises a first connection element for rotation with the turbine and a second element connection arranged to be non-rotating and be connected to the cable to a remote location. There may also be provided a support arranged to be fixedly connected to the ground in fluid flow, wherein the support comprises an elongate member having a top end and a bottom end, the portion of the support adjacent the top end having a reduced cross sectional area to the bottom end. There may also be a generator for a marine turbine comprising a rotor arrangement and stator arrangement wherein the generator is flooded with fluid in which the marine turbine is immersed. Additionally or alternatively, the rotor and/or the stator are provided with a matrix, layer and/or coating to provide a fluid sealing function. There may also be provided an axial load bearing assembly including a braking means arranged to control rotation of the shaft.

Guillaume [72] used a long horizontal axis rotor to extract energy from tidal currents. Inlet and exit funnels may be provided to guide flow over the rotor, and there may be a mesh to prevent debris or large creatures accessing the rotor. Two or more contra-rotating rotors may be linked in series. The rotor may drive a hydraulic pump to transfer energy generated to shore or to a surface platform. Christopher et al. [73] described a tidal flow turbine has a rotor with fixed attitude turbine blades. The stagger angle of the blades (solid line) is such that over a lower operational speed range of the turbine, axial loading increases as rotational speed increases, but above a predetermined threshold, axial loading on the turbine does not increase. The maximum axial load may be exerted at a rotational speed below the free-wheeling speed of the rotor.

Donald [74] presented a vertical axis turbine comprises a rotor having blades, which are mounted to move relative to the rotor during its rotation such that the rotor rotates in the same direction irrespective of direction of the fluid flow in the horizontal plane. The blades may have a hydrofoil shape and be arranged such that the force of the fluid flow, and the force generated by the hydrofoil shape, causes each blade to rotate about a vertical axis between a vertical shaft of the rotor and a stop. The turbine may be driven by tidal flow, and may drive a hydraulic or electrical device such as a generator. The vertical shaft may also be used as a fixing pile.

Dass et al. [75] disclosed a turbine assembly and a system for extracting tidal energy. The turbine assembly may include identical sections disposed in a stacked arrangement. Each section may be shaftless, energized by a fluid flow to produce lift and is appropriately oriented at a phase shift to an adjacent section such that a relatively constant resultant torque output with small amplitude fluctuation is generated by rotation of the turbine assembly. The turbine assembly may be employed in conjunction with a velocity enhancing device having housing with variable profile openings to enhance the torque output. The turbine assembly may further be employed in a floating barrage arrangement which is transportable.

Jack et al. [76] provided a method for controlling the alignment of a tidal stream energy device. The method includes repeatedly performing at intervals the steps of: measuring the tidal stream flow direction at the device, determining the alignment of the device, comparing the measured flow direction with the determined alignment to determine whether the device is misaligned with the measured flow direction, and changing the alignment of the tidal stream energy device when the comparison shows a misalignment so that the device is better aligned to generate energy for the measured flow direction. The interval is preferably at least 2 minutes and the flow direction can be measured over a volume. The flow direction is monitored to detect anomalies and the flow direction measurement can be adjusted to compensate for the anomalies.

7. Future prospects of harnessing tidal current energy in Malaysia

Electricity demand in Malaysia is projected growth, the demand for electricity is increased from 91,539 GWh in year 2007 to 108,732 GWh in year 2011
[77,78]. Accordingly, it is forecasted that by 2020, the final energy demand in Malaysia will reach 116 Mtoe based on an annual growth rate of 8.1% [79]. With the rapid development, Malaysia requires more and more resources to support the development and to enhance the productivity of capital, labour and other factors to production.

7.1. Tidal current energy resources in Malaysia

A tidal current turbine is very much depending on tidal current speed and water depth. From literature, the ideal marine current speed to make the turbine work is at least 2 m/s (4 knots). However, the averagely current velocity in Malaysia is only 1 m/s (2.0 knots) [80], which is half of the speeds for which turbines have been developed in other countries. To develop a turbine in a low current speed, a big system of turbine is needed. The problem, however, lies in the blade diameter, which is limited to water depth. Therefore, some modification must be made on the current speed or the turbine itself, or both to enable the turbine to work in low current speed.

In Malaysia, study on ocean based energy sources is still in the infant stage. Very few and limited studies were found in the literature and most of them are assessment studies. In one of these studies, Lim et al. [81] used a three-dimensional ocean

model of Malaysia which was created in the Princeton Ocean Model (POM) and calibrated against observed tidal measurements. The authors carried out an analytical assessment to estimate the amount of electricity to be generated by tidal current turbines and also to evaluate the economical viability and environmental benefits of installing tidal current turbines in Malaysia. It was identified that Pulau Jambongan, Kota Belud, and Sibu are the locations with great potential for tidal energy extraction. The total amount of electricity that can be generated by MCTs on those locations is about 14.5 GWh/yr. According to the authors, this amount is much higher than the amount of electricity of photovoltaic systems which is aimed to be generated in 2010. The government or utility company can save about RM 1.1 billions of natural gas and avoid a total greenhouse emission of 4,552,512 t/yr.

7.2. Other renewable energy resources in Malaysia

Malaysia's electricity sector is dependent on fossil fuel sources. In 2009, almost 94.5% of electricity is generated by using fossil fuel such as natural gas, coal, and oil. The balance was generated by hydroelectric [82].

On 2009, Malaysia formulated the National Green Technology Policy to reflect that Malaysia's seriousness in driving the message that 'clean and green' is the way towards creating an economy that is based on sustainable solutions. It will also be the basis for all Malaysians to enjoy an improved quality of life. The government wants to promote green technology usage to push for economic growth in the new economic model [83].

Renewable energy sources, most notably, Biomass, wind energy, solar energy and small scale hydro power schemes have undergone major development. One other form of renewable energy which has attracted great interest is tidal current energy. This energy resource has a great potential to be exploited on a large scale because of its predictability and intensity.

Currently, there are a number of RE projects in Malaysia, which are Small Renewable Energy Power Program (SREP), Malaysia Building Integrated Photovoltaic (MBIPV) Systems known as (SURIA 1000) program, Hybrid Solar Systems for rural electrification.

Small Renewable Energy Program (SREP) was launched in 2001. Under this program, small power generating plants which utilizes renewable energy can apply to sell electricity to the largest electricity utility company in Malaysia which is Tenaga Nasional Berhad (TNB). To date, the total approved generating plants are 60 with total capacity of 353 MW (Table 1). Many of the approved renewable power plants under SREP scheme use biomass, wood waste and rice husk as a source of energy.

As noted by [84], 185 projects related to the development of technologies focusing on harnessing energy from resources such as solar, hydro, wind and tidal waves costing RM 158 million have been done. Relatively, Malaysia develop a renewable energy technology roadmap in five significant focus areas including biomass, solar, wind, micro-hydro and tidal power.

Table 1
Projects under SREP.

Types	Sources	Approved	Capacity (MW)
Biomass	**Palm waste**	**22**	**200.5**
	Wood waste	**1**	**6.6**
	Rice husk	**2**	**12**
	Municipal solid waste	**1**	**5**
	Mix	**3**	**19.2**
Landfill gas		**5**	**10.2**
Mini-hydro		**26**	**99.2**
Wind, solar and tidal		**0**	**0**

8. Conclusion

The tidal energy sector is currently characterized by a large number of concept devices. An increasing number of these technologies have attracted investment and progressed to full-scale prototype testing. The technology for tidal turbine systems is already available and there is no doubt, given the experience accumulated, that the resource in Malaysia is substantial and available. Tidal-current systems will offer opportunities for supplying energy in rural, coastal and island communities.

Despite the continuous effort to improve on renewable energy, they are not yet utilized to their maximum potential in Malaysia. Government, non-government agencies and the public will have to take a more proactive step to promote and use renewable resources energy to increase a wider utilization of renewable energy in Malaysia. However, the potential of harnessing tidal current energy, in Malaysia has not been fully realised. Therefore, this study was carried out to identify the potential of harnessing this renewable resource for electricity generation.

Tidal energy is a promising renewable energy source available in Malaysia. The results of this paper and the authors' future work may encourage the government to provide additional research funding for design, development, erection and installation of tidal current turbine prototypes.

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